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Polish Cartographical Review
Vol. 51, 2019, no. 4, pp. 155-165
DOI: 10.2478/pcr-2019-0013
Received: 30.10.2019
Accepted: 06.12.2019

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Selected qualities of mobile maps for indoor navigation

Abstract. The map is the key element in any navigation system. The dynamic growth of indoor navigation systems requires improvements in quality not only of positioning systems but also of maps of building interiors. Most emergent solutions in this field do not use cartographic knowledge. Cartographic methodology for representing building interiors is still in its initial stages of development. Its proper use may, however, be of great importance to the effectiveness of indoor navigation. The author presents important features that indoor mobile maps should possess, for both the data model and the presentation method to be used. In this context, the question of the contemporary definition of a map is also discussed.

Keywords: indoor cartography, mobile cartography, mobile maps, indoor navigation

1. Introduction

The quality of modern location-based services depends to a great extent on the quality of the maps used. This also applies to indoor navigation systems currently under development. Much work is being done to improve positioning quality and routing algorithms, and to develop appropriate voice or text guidance. It seems, however, that too little attention is still being paid to the quality of the map itself and to the proper application of cartographic methods. Cartographic theory has not fully kept up with technological progress in this regard. For this reason, it is worth carrying out in-depth research into maps used in indoor navigation systems. While map-making methods for marine, aviation or automotive navigation systems have been mastered, there is no widely available literature on the development of indoor navigation maps. This is well reflected in the literature review presented by J. Chen and K.C. Clarke (2019). For many years, the mapping of building interiors was not the domain of cartographers. This was due, among other things, to the fact that presenting building interiors did not serve the tasks and functions of cartographers, but rather those of architects, building engineers and property managers. This state of affairs is currently undergoing significant change. Increasingly, there is a need for a spatial model to help users navigate or familiarize themselves with spaces in a way that is not readable to a narrow group of specialists only, but to a wider audience. In this case, the role of cartographers becomes crucial. Shoppers, travellers, conference-goers and hotel guests now need information about a building interior to be displayed in a similar way to information about the building's surroundings. Mobile maps used in systems that function both outdoors and indoors should be integrated, allowing the concept of seamless navigation to be achieved. To this end, a unified cartographic methodology is required.

2. Research methodology and source data

Experiments based on the created spatial model of the complex university building provided the basis of the research. The model was created by transforming classic architectural and construction drawings and performing additional surveying and laser scanning. CityGML, IndoorGML and BISDM (Building Interior Space

Data Model) standards were used as well as authorial extensions and modifications of these models. The model was used in numerous studies and development works on various topics: from work on property management to work on the optimization of the navigation process (D. Gotlib et al. 2012). As part of the research, many visualizations of various interiors of buildings available on the Internet were analyzed. Then, a series of visualizations were made for the test building and they were evaluated on mobile devices. These experiments revealed shortcomings in the methodology of the visualization of building interiors. An analysis of several years' worth of literature showed the lack of clear guidelines that could have eliminated the deficiencies noted. Using the analysis of cartographic literature, and in particular, literature in the field of mobile cartography and indoor navigation, an attempt was made to systematize the features of mobile maps used in indoor navigation.

3. The methodology of mobile cartographic presentations

According to definition proposed by T. Reichenbacher (2001, 2004), mobile cartography is the field of cartography which deals with theory and technology related to the dynamic visualization of spatial data and their use by mobile devices, anywhere and at any time, with particular regard to real-world context and user preferences. Many of the key methodological considerations in this area can be found in publications including: G. Gartner 2000, 2009; F. Nissen et al. 2003; T. Morita 2005a, 2005b; G. Gartner et al. 2007a, 2007b; H. Huang, G. Gartner 2010.

The concept of the mobile map is generally understood as an electronic map used on a mobile device. It is usually a component of location-based services. It is worth noting here that a map is not a graphic image, but an appropriately defined, special structure of information (M. Baranowski et al. 2017). A map is a model-based representation of reality created using symbolism which is comprehensible to users.

Understanding how to use electronic maps on mobile devices such as PDAs, PNDs, tablets and smartphones is key to creating "effective maps for mobile computing" (J. Dillemuth 2007). This statement must be considered as fully justified. The specifics of how mobile systems – and navigational systems in particular – are used fundamentally affects the selection of data and how it is communicated to the user.

The specificity of creating cartographic presentations for mobile systems results primarily from the following conditions (D. Gotlib 2011):

− the need to move and rotate the map image during use;

− the need to observe the terrain image at different scales;

− the very limited option to use a map legend;

− impediments to viewing the cartographic presentation (changeable lighting conditions, limited observation time, light reflections from the screen, small screen size);

− differing representations of colours between different devices, related to the specific natures of screens and projectors;

− the need to display dynamic information (route, obstacles, weather, advertisements, etc.) depending on the location and behaviour of the user;

− the limited performance of mobile devices.

In order to define the key mobile map features that should be used in indoor navigation systems, it is worth analyzing the desirable features of all mobile maps.

In describing the features of the maps of the future, created in accordance with the concept of ubiquitous mapping, T. Morita (2005a) uses a model in the form of a cube. This model is built on the analogy of three orthogonal axes, defined by C. Morris (1960) as semantics, syntax and pragmatics. In Morita's cube the axes are labelled "media" (flexible), "spatial representation" (multi-dimensional) and "spatial articulation" (individual). Higher values on the "spatial articulation" axis represent an increase in the individual nature of a cartographic presentation; higher values on the "spatial representation" axis indicate a presentation's multi-dimensionality, and increased values on the "media" axis denote the possibility of using a greater number of media to ensure correct cartographic communication. In this model, contemporary mobile cartographic presentations should be placed near the corner that is the furthest from the origin of the coordinate system.

In D. Gotlib (2011) the following key qualities (features) of cartographic presentation adapted to the needs of mobile navigation and location systems were proposed: *egocentrism, multi-*

mediality, multi-scalability, polymorphism, contextuality, dynamism, interactivity, universality, self-explaining, glanceability and optimality. Modern, useful and attractive cartographic presentations should have all, or at least most, of these features.

In the research described in this article, the thesis was proposed that these features should also be met by presentations used in indoor navigation.

Knowledge and the significance of these features are important for the proper development of an indoor mobile cartographic presentation model, and then for the design and proper use of correct cartographic representations. Therefore, further consideration of the key features of mobile maps for indoor navigation will refer to the described set of features.

4. The indoor navigation map

4.1. The specifics of the indoor navigation map

According to the statement by J. Dillemuth (2007) cited earlier, before beginning the design of a mobile map (in this case, the map of a building interior) it is necessary to understand how the user will use the map. Clarifying the dividing line between indoors and outdoors is vital to the development of indoor maps (J. Chen, K.C. Clark 2019). As with other navigation applications, the user moving inside the building (usually a pedestrian) reads the map on the move on the small screen of a mobile device while also observing the surroundings. The user expects their position and route to be displayed at different levels of detail depending on the situation and the stage of navigation. During navigation, the user receives navigational guidance and various forms of additional information. The user's perception is usually negatively affected by local environmental phenomena. These include, for example, the movement of other people or vehicles, noise, unfavourable lighting and instability of the mobile device (shaking).

For indoor navigation systems there are particular conditions that need to be heeded and analyzed. For example, the noise in a shopping centre may be an impediment to receiving voice navigation messages. Conversely, voice guidance emitted by the app may cause an even greater nuisance to other people in the building. It is easy to imagine the discomfort of several people simultaneously using navigation at a conference, during hospital visits, or when moving around a shopping centre. A different, but equally important issue is the specific way in which the user moves. The movement of the user inside the building is often not as orderly as movement by car, air or sea. The pedestrian makes frequent turns, and often turns around freely (to look, for example, at an exhibit or signage). This is a major challenge for positioning systems, routing algorithms, and algorithms for generating directions. The need to almost constantly hold the mobile device in the hand is also not insignificant. The mobile system user's time spent observing the map and taking decisions is presumably short. It should also be noted that in addition to the usual pedestrian routes, there are open spaces, lifts, stairs, escalators, and obstacles in the form of doors, gates across entrances, and hazards such as the thresholds of doorways. For some users (special and emergency services) additional impediments to using the application may include smoke, fire, lack of light, and physical obstacles in the way, such as furniture. When using paper maps or electronic maps displayed on desktop computers, most impediments to the transmission of information do not occur. When designing a mobile map for indoor navigation, it is important to note that a building interior usually has a much larger number of objects per given unit of area. There is a growing necessity to map the position of objects with greater accuracy than in other applications. At certain points during navigation it also becomes necessary to connect the visualization of the building with its surroundings in as seamlessly integrated a way as possible for the user.

As previously mentioned, the specific nature of mobile mapping for indoor navigation is influenced by the way that people usually move on foot in a building. It is not practical (or convenient) to count steps or calculate the exact distance from where the user is to where a manoeuvre must be carried out. A user in a building must often avoid obstacles (people, furniture, exhibits) along the way, and there is usually no way to get real-time updates on distance travelled. Therefore, the logic of navigational directions generated by the application should

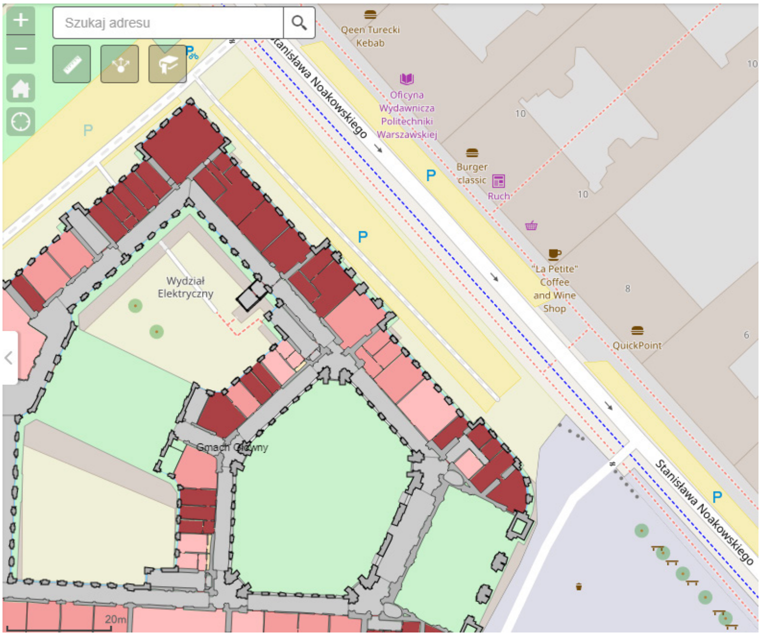

Fig. 1. The results of the attempt at "seamless" presentation of the interior of a building and its surroundings (prototype of the spatial information system of the Warsaw University of Technology, own data and OpenStreetMaps)

be different: instead of notifying of a turn in 15 or 30 metres, the system should provide descriptive information about the vicinity of a turning point and how to get past the next waypoint, such as, "go to the lift in the main hall; go to the 4th floor; after exiting the lift, turn right into the 'Manhattan' gallery, and then, after the ATM, turn left; your destination is on the right". This type of analysis has already been conducted in a several of works, including I. Fellner, H. Huang and G. Gartner (2017).

4.2. The source data model

The quality of the building model determines both the quality of the entire navigation process and the very method of presenting the data. We should understand the idea of the building model as encompassing both the conceptual model and the specific set of source data. In terms of conceptual models, there are currently different approaches to building interior modelling, but the use of CityGML (LoD 4) and IndoorGML models predominates. Neither of these models meets all the requirements of navigation applications. Each was designed for a different purpose and only by properly integrating them and through supplementation or extension would it be possible to provide the information set needed by a building interior navigation application. In terms of source data, architectural and building plans as raster images (scans of maps) and CAD vector files are most commonly used as the foundation of a building model. The use of BIM (Building Information Modelling) models and TLS (Terrestrial Laser Scanning) point clouds is less common. This is due, for now, to their limited availability. They also often require a classic architectural and construction inventory to be made and additional geodetic measurements to be taken. A BIM model requires a number of transformations in order to be used effectively by GIS systems and in navigation applications. Many concepts on this subject can be found in U. Isikdag et al. (2013). Comprehensive use of many data sources allows a model of the highest quality to be built, i.e. a model containing: an appropriately detailed description of the building topography; the location and description of the building's technical infrastructure and equipment; information on permissible pedestrian and vehicular thoroughfares; information on estricttions (e.g. employee-only zones, architectural barriers to people with disabilities); and information on the functional use of rooms, etc.

Without a proper structure of data, relationships and attributes, it is not possible to make cartographic presentations possessing all the features described in sections 2.2 and 2.3. If the database contains no information on room height, 2.5D or 3D presentations cannot be produced. If the database does not contain the appropriate relationships between rooms, usable floor areas, and storeys and sections of a building, then it will not be possible to easily represent them at different levels of generalization. The lack of properly (smart) modelled traffic flows within the building will prevent proper cartographic presentation (D. Gotlib, J. Marciniak 2012). The issue of modelling building interiors itself, however, is beyond the scope of this article.

4.3. Features of mobile cartographic presentation of building interiors

The issue of the cartographic aspects of indoor navigation application design has been discussed in the literature (A. Puikkonen at al. 2009; H. Huang, G. Gartner 2010; A.S. Nossum 2011; A. Lorenz et al. 2013; J.M. Krisp et al. 2014; I. Fellner et al. 2017).

D. Gotlib et al. (2012) state, *inter alia*, that "appropriately developed geovisualization should ensure: (1) high readability of the presentation in motion and easy orientation in a building, (2) the presentation of a building at a number of levels of detail, (3) the correct geovisualization of a route, (4) the visualization of the user's position in the background of the topography of a building, (5) contextuality of the cartographical message".

The research described in the paper attempts to define the basic assumptions of mobile maps for indoor navigation, considering the conditions and features of mobile applications mentioned in section 3. Below, we look more closely at some of the recommendations and detailed concepts resulting from those studies.

Egocentrism in mobile maps for indoor navigation, as with other types of navigation, means that user behaviour crucially influences the message conveyed by the application. The importance of this feature to cartographic methodology is emphasized by L. Meng (2005), among others, indicating a move in cartography away from a carto-centric view to an egocentric or user-centred view. A. Zipf and K.F. Richter (2002), meanwhile, call this type of cartographic presentation "ego-maps". The mobile map design and navigation application design must take into account the following conditions, among others:

1. A change in user trajectory usually causes simultaneous rotation of the image. However, attempts should be made to detect the type of user motion. For example, if it is chaotic, low--speed motion (which may indicate that the user is looking around) the image should not be rotated. Similarly important for imaging would be, for example, to determine that the user is in a lift. Such information should have an appropriate impact on the visualization (e.g. "freezing" it) until the lift comes to a stop and the user exits.

2. A change in speed by the user, or proximity to specific locations, can cause a change in the scale and content of the presentation, as well as resulting in the application generating navigational voice directions, voice descriptions of locations, or multimedia marketing information. Detecting the user's proximity to an exhibit should trigger, for example, image zoom and the playing of an audio description. At the same time, detection of a museum or temple interior should either disable audio or require the use of headphones. Meanwhile, the detection of high-speed movement (of the user) should limit the display of marketing or touristic voice messages.

The cartographic presentation cannot be based on a static image of a building, or on data at a single scale. Descriptions must be generated dynamically. The cartographic symbol showing user position and planned trajectory should take precedence over the other cartographic symbols used, while at the same time working harmoniously with them. These are, of course, the rules of all navigation applications. Particular to indoor navigation is the intelligent displaying of relevant "floor plans" for the storey the user is on (or the storeys the user is between).

Fig. 2. The example of AR geovisualization of the route in the building (source: Blippar launches indoor visual positioning system [...], 2018)

The way the floors are presented is not a trivial issue when the user is in a lift. During navigation, it is also necessary to present the user position in the context of the whole building at certain times. In this case, it is usually necessary to use an axiometric view. In 3D visualizations, presentation methods should be used which make the user's position visible, even though the observer is actually obscured (by using "transparent" walls). Because of the small screen size, it should show the part of the building in which the user or the planned route is currently located. The presentation method is therefore strongly dependent on the position of the user.

Multimediality is a fairly obvious feature of modern mobile cartographic presentations. At present we can find many innovative approaches such as 3D maps produced using WRLD3D (www.wrld3d.com), indoor panoramic images, VR (virtual reality) visualization or AR (augmented reality) (fig. 2).

The cartographic message should be communicated using multiple simultaneous means of expression, to increase its usefulness and attractiveness, and often also its readability. In the case of indoor navigation, this feature can be achieved by, for example, displaying at the same time a classical graphical floor plan of a building, a panoramic view (photographs) and the generation of audio descriptions of exhibits in the museum or voice advertisements of the stores the user passes. For systems where the application's use of sound effects may be a problem for other people, certain information might be communicated by the vibration of the mobile device. Of course, the problem of navigation application "noise" can be eliminated by using headphones, but this is not always possible or convenient.

The *multi-scalability* of a cartographic presentation fundamentally impacts the usability of a navigation application. In the vast majority of cases it is not possible to simultaneously represent the whole building in all its detail. It is necessary to prepare presentations of the building interior at several scales (fig. 3). The user needs a view not only of the building and its surroundings, and of each floor, but also a detailed visualization of a given room, often with equipment (furniture, exhibits, etc.).

The quality of a navigation application can be determined by smart scaling algorithms that can use one or more source models for a building and its surroundings. A proper multi-scalable presentation also creates the possibility for seamless navigation between the building interior and exterior. Multi-scale 3D presentation is a particular challenge. The inability to display all floors in 2D at the same time is specific to indoor navigation applications. This issue is, in and of itself, an interesting and difficult task for cartographers.

Polymorphism as a feature of the cartographic presentation of a building interior for navigation applications is particularly evident when presenting a building in 2D and in 3D (or axiometric) view or while changing image scale.

Fig. 3. The multi-scale geovisualization of the interior of a building for navigation purposes

The same building elements must be presented in a different way (fig. 4). The same building can be displayed using different colours and graphic symbols according to user preferences (pastel, high-contrast or greyscale palettes, etc.). This feature is typical of all navigation systems.

Contextuality is one of the most important features of modern mobile maps and will probably play an increasingly important role in determining the attractiveness and usefulness of applications. It is closely related to the egocentric feature. Contextuality (context-awareness adaptation) of presentation derives from the need to adapt the content and form of the cartographic message to a specific place, to specific user behaviour, or to user preferences. H. Huang and G. Gartner (2010) have defined this concept ("context") as follows:

1) something is context because it is used for adapting the interaction between the human and the current system;

2) activity is central to context;

3) context differs in each occasion of the activity.

Cartographic presentation should be also modified as a result of specific relationships between the user and the environment.

Depending on whether a user in a shopping centre is present as a customer or as a technician, the cartographic presentation should display different information and display it in a different form. In the first case the key information provided to the user may include names of stores, categories of products sold in them, and promotions currently available (or discounts held by a person in a store). In the second case, the key information is about technical installations, property owners and reported faults. In the first case they do not have to (and even should not) be shown the interiors of spaces to which customers are not granted access. In the latter case, all interiors should be presented. For the centre's return customers, the important information will be about changes in store stocks since their last visit, while for the centre's first-time visitors this information will be superfluous. Of course, these are only the simplest of examples.

Fig. 4. The example of indoor presentation in 2D and 3D (prototype of the spatial information system of the Warsaw University of Technology) (author's elaboration after M. Gnat's materials)

The *dynamism* of cartographic presentation in building navigation applications, as in other types of navigation, is manifested in continuous changes in the scope and scale of the presentation. The process of displaying names and descriptions of objects and places is dynamic. In mobile cartographic presentations, labels cannot have a fixed location; their placement varies according to scale, image orientation and user location. Developing a good algorithm for generating labels is not a simple task, just as in cartography the editor's task of arranging labels on a traditional paper map was never simple. The presentation is not therefore fundamentally static, except for the simplest applications based, for example, on raster maps. In addition, the selected information is displayed in real time. Inside buildings, this will not be traffic information, although it might be considered potentially useful, such as information about the length of check-out queues at a given moment. It will far more commonly concern the presentation of marketing information (e.g. current product promotions), information about museum exhibits, the starting of a conference session, or messages related to passenger traffic at air- and seaports and railway or bus stations (e.g. the opening or closing of check-in for passengers for a particular gate at the airport). One interesting solution may be to show the movement of transportation vehicles in real time or when they are stopped (e.g. a train entering a platform).

Interactivity, in turn, is a feature common to all the mobile cartographic presentations used in all types of navigation (and GIS application). One of the characteristic features for indoor navigation not seen in other navigation is the user's ability to switch between different floor views.

Universality of indoor navigation can be manifested in its being developed to be appropriately read by a variety of mobile devices (smartphones, smartwatches, tablets, laptops), desktops (web browsers), and information kiosk screens. Some users may also be interested in a traditional print-out of a floor plan or route to a selected room.

Self-explaining is an aspect of readability and is used here to refer to the feature of cartographic presentation that ensures accurate reading of information without the use of a map legend. From the perspective of the user of a navigation system, the condition of *self-explaining* is certainly not met by architectural construction drawings. The map of a building's interior used during navigation must be much simpler and use cartographic symbols which are easily associated with real-world objects. One example might be the use of shades of green to indicate all accessible routes and pathways in a building, and shades of red for limited-access ones (fig. 2). It may be helpful to use blue to indicate glazed elements in a building. As with other types of navigation, it is important to properly design and use PoI (Point of Interest) signatures (ATM, restaurant, toilet, etc.). The number of symbols, colours, shapes and patterns used in the presentation must not be too large.

Glanceability (perceptibility) is the feature of mobile cartographic presentation which allows the user to read the cartographic message in a very short time, often in a brief glance at the map while performing one of a range of other activities, such as walking through a shopping centre. The cartographic presentation of the building interior must be adapted for several levels of reading. In the planning stage of a route between several buildings, there is, for example, no detailed presentation of room layouts. Meanwhile, when correcting the user's route during navigation, even interior equipment needs to be displayed (that within close reach of the user). Graphic symbols used in presentations must have relatively simple graphics and be of appropriate size.

Optimality of cartographic presentation in navigation and location applications is an essential feature for ensuring proper performance of the mobile system (device plus application). *Optimality* is ensured by the appropriate selection of content and communication media. Displaying and performing operations on a full BIM model or on a point cloud from a laser scan, for example, would not be an optimal solution on a mobile device. For navigational purposes of this type, an exact building model is not required. What is needed is a generalized and processed model. The content of the database is usually much richer than is needed for presentation at any given moment. The designer of mobile cartographic presentations should keep this in mind and optimize the selection of content depending on what the user is doing. Table 1 presents the result of the analysis of differences between cartographic presentation in a mobile indoor application and architectural and construction drawings in CAD.

Table 1. The comparison of the significance of selected presentation features for cartographic presentation in a mobile indoor application and architectural/construction drawings in CAD

Presentation features	**Mobile indoor cartographic presentation**	**Architectural/ construction drawings**
Egocentrism	+	-
Multimediality	+	+/-
Multi-scalability	+	+/-
Polymorphism	+	+/-
Contextuality	+	-
Dynamism	+	-
Interactivity	+	+/-
Universality	+	-
Self-explaining	+	-
Glanceability	+	-
Optimality	+	-

"+" indicates a feature is typical for the given type of presentation,

"+/-" indicates that a feature can be considered relevant in some cases,

"-" indicates that it is not typical

It should be noted, however, that a presentation that meets the features discussed above cannot always be considered cartographic. It is necessary to meet additional conditions, such as the portrayal of space, identification of types of objects and phenomena, description of spatial relationships between objects, localization in an applied reference system, deliberate choice of a certain level of generalization compliant to the map's objective, symbolization based on knowledge, aware authorship of the message, and explicitness of communication (M. Baranowski et al. 2017).

5. Conclusions

Cartography is increasingly looking towards unmapped spaces: the planets, beneath the oceans, and in the earth's interior, but also the interiors of buildings (K.C.Clark et al. 2019). Indoor maps will be increasingly in-demand marketed products. Cartographers should be developing cartographic methodology to ensure that this product will meet the needs of users and be the key element in a navigation application.

Presentations that fulfil features discussed above have the potential to meet the growing needs of users, and cartographers can play an important role in the indoor navigation market. In practice, not every presentation has all of the features described. Not employing one or two features does not mean that the presentation cannot be referred to as "correct" . Rather, we should use the theory of fuzzy sets, that is, allow certain features not to have to be perfectly fulfilled. However, the aim should be to create presentations with as many of the listed features as possible.

The considerations and proposals presented touch on only a few of the issues that cartographic methodology should encompass. Other issues include a formal definition of mobile cartographic presentations (conceptual modelling), and the issues of presentation graphics, coordinate systems, cartographic algorithms supporting navigation functions, and how to formulate directions and voice descriptions of indoor spaces.

Research is required into indoor cartography. Innovative scientific and technological solutions must be sought, but the basic principles behind the construction of a correct cartographic message can be found in existing cartographic theory.

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